California's Success in Reducing $PM_{2.5}$ Pollution

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California has made remarkable progress in reducing fine particle pollution in the nation's most challenging nonattainment regions, the South Coast Air Basin and the San Joaquin Valley. This article outlines the state's success.

Since 2000, annual concentrations of fine particulate matter (i.e., particles less than 2.5 micrometers in diameter or $PM_{2.5}$) have dropped approximately 50% in the South Coast Air Basin (SC) and the San Joaquin Valley (SJV) and both regions are expected to attain the annual standard of 15 $\mu g/m^3$ by the 2014 deadline. Compliance with the 24-hr standard of 35 $\mu g/m^3$ is projected in SJV by the 2019 deadline and in SC by 2014. The downward trend in the peak annual average $PM_{2.5}$ concentration in California's major urban areas is shown in Table 1.

As noted in John Bachmann's introduction to this issue (page 6), particles are a complex and variable atmospheric mix, and California's emission control programs have successfully targeted the most significant emission sources. While $PM_{2.5}$ attainment strategies have varied somewhat in different locations, the major strategies have included California's longstanding oxides of nitrogen (NO_x) control programs; statewide fleet rules to reduce both NO_x and PM from diesel engines; the phase-out of most open burning; and the implementation of episodic controls for residential wood-burning.

Implementation of the diesel fleet regulations adopted by the California Air Resources Board (CARB), and a variety of state and regional incentive

Exeter, CA, in the San Joaquin Valley (SJV).

Table 1. Trends in the peak annual average $PM_{2.5}$ concentration in California's major urban areas.

Region	Peak Annual Average $PM_{2.5}$ 1999–2001 (µg/m³)	Peak Annual Average $PM_{2.5}$ 2010–2012 (µg/m³)
San Joaquin Valley	24.7	16.0
South Coast Air Basin	29.8	15.6
San Diego County	17.1	10.8
Sacramento Region	15.4	9.5
San Francisco Bay Area	14.2	9.3
Ventura County	14.5	9.0

programs, is cleaning up diesel engine fleets at a rapid pace, far exceeding natural turnover. These fleet rules are the most significant single strategy for achieving new emission reductions in the attainment demonstrations for annual and 24-hr $PM_{2.5}$ standards in California. Between 2005 and 2012, statewide emissions of $PM_{2.5}$ from diesel engines were reduced by approximately 35 tons per day.

SJV can be used as a case study to illustrate the scientific challenges in designing the most effective control strategy to meet the 24-hr $PM_{2.5}$ air quality standard. Extensive research and technical assessments support the 2012 State Implementation Plan (SIP) for the 24-hr $PM_{2.5}$ standard prepared jointly by CARB and the San Joaquin Valley Air Pollution Control District (SJVAPCD). A similar effort was carried out by the South Coast Air Quality Management District (SCAQMD) in preparation of its 2012 Air Quality Management Plan.[1] With implementation of the adopted $PM_{2.5}$ SIPs for SC and SJV, and the downward trend in $PM_{2.5}$ and its significant precursors, California is also well situated to comply with the new annual $PM_{2.5}$ standard of 12 µg/m³ by the federal deadline.

SJV Case Study

SJV is well known for its geographic setting and meteorological regime that is very conducive to the formation and trapping of air pollution. It is bordered on the west by the coastal mountain ranges and on the east by the Sierra Nevada range. These ranges converge at the southern end of the basin at the Tehachapi Mountains. Of the eight counties in the region, the southern and central counties experience the most severe air pollution. The region, approximately 64,000 km² in size, has a population approaching four million. The Fresno urban area in mid-SJV has a population of approximately 500,000 and the Bakersfield urban area in the south has a population of approximately 350,000. The remainder of the population is distributed in small to mid-size cities ranging in population from 2,000 to 300,000.

Due to its challenging air quality problem, the SJV air basin is one of the most studied areas in the world. The region's agricultural and oil industries were recognized early on as important contributors to air pollution, along with passenger vehicles and commercial transportation. A series of ozone and PM field studies, including the comprehensive California Regional Particulate Air Quality Study in 1999–2001, has provided extensive data sets enhancing understanding of SJV's emission sources, atmospheric chemistry, meteorology, and the effectiveness of controls put in place over the past decades. The studies provide the foundation for predicting future air quality as emissions decline each year, and the relative effectiveness of potential new emission control strategies. The $PM_{2.5}$ attainment strategy for SJV reflects these key findings: $PM_{2.5}$ is a wintertime problem, ammonium nitrate and carbon constituents dominate, ammonia is abundant so NO_x control is most effective in reducing ammonium nitrate, and residential wood combustion is a significant contributor to 24-hr $PM_{2.5}$ concentrations.

Over the years, these findings have been incorporated into the development of $PM_{2.5}$ control strategies that have improved air quality, and put the region on a path toward compliance with federal

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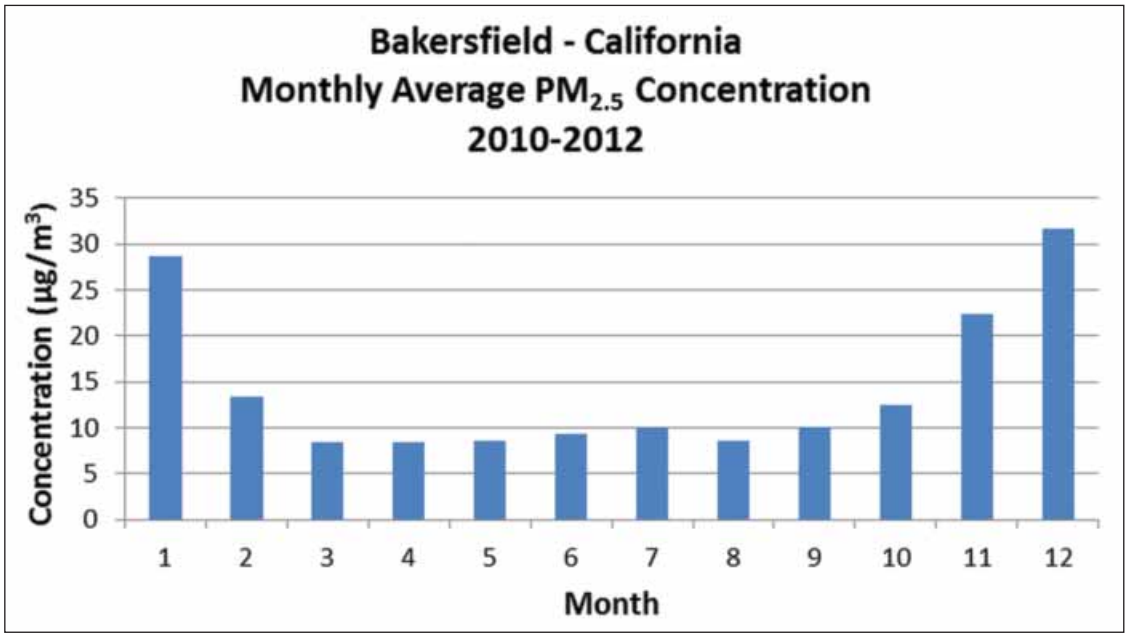

Figure 1. The monthly average $PM_{2.5}$ concentration at the Bakersfield – California Street monitoring site in the SJV, during 2010–2012.

air quality standards by the mandated deadlines. SJV is close to meeting the 1997 annual $PM_{2.5}$ standard with a current design value of 16 µg/m³. The 24-hr $PM_{2.5}$ SIP demonstrates that 90% of SJV residents will live in communities that meet the daily standard by 2017, with full compliance projected by the 2019 deadline.

SIP Modeling

The SJV 2012 $PM_{2.5}$ SIP[2] is designed to address the specific nature of the remaining violations of the 24-hr standard. Although 24-hr $PM_{2.5}$ concentrations have decreased 30–40% over the past 10 years, the current design value is significantly above the daily standard of 35 µg/m³, with a value close to 60 µg/m³. As shown in Figure 1, $PM_{2.5}$ concentrations in SJV exhibit a strong seasonal pattern, with concentrations over the 24-hr standard occurring during the winter months. Cold temperatures, fog, stagnant airflow, and extended periods without rainfall results in episodes of elevated $PM_{2.5}$ that can persist for a week or more. Multiple episodes can be observed in SJV during the winter, punctuated by weather fronts that result in improved dispersion. Region-wide concentrations of ammonium nitrate contribute to $PM_{2.5}$ violations, with localized, episodic activities such as residential wood-burning adding to the pollution burden in the wintertime. The $PM_{2.5}$ concentrations are generally higher in the southern and central portions of SJV, with highest values recorded in the urban areas of Bakersfield and Fresno.

The average chemical composition on high $PM_{2.5}$ days during 2010–2012 is shown in Figure 2. Secondary ammonium nitrate formed from NO_x and ammonia precursor emissions is the most prevalent component at both sites, accounting for more than half the average total $PM_{2.5}$ mass. Carbonaceous matter is more prevalent in Fresno (34%) compared to that in Bakersfield (21%). This difference can be attributed to the greater impact of residential wood-burning in the Fresno area during the winter months. Together, ammonium nitrate and carbonaceous matter account for approximately 90% of the mass observed on average high $PM_{2.5}$ days. Other minor components include ammonium sulfate, geological materials, and trace elements. The very low sulfate contribution in $PM_{2.5}$ (compared to the eastern United States) is primarily due to the small percentage of sulfur in California fuels and the lack of significant coal-burning.

Understanding the nature of the remaining $PM_{2.5}$ problem provided the basis for the 2012 SIP modeling and development of the required attainment demonstration. The SJV 24-hr SIP attainment demonstration relies primarily on the new reductions in directly emitted (or primary) $PM_{2.5}$ and NO_x resulting from implementation of California's adopted regulations and programs. As a result of these programs, between the SIP base year of 2007 and 2019, NO_x emissions decrease 55% and direct $PM_{2.5}$ emissions decrease 30%. These

emission reductions, combined with enhanced wood-burning restrictions, provide the attainment demonstration for the entire region except the Bakersfield urban area. This modeling showed that by 2019, all monitoring sites except one in Bakersfield would have design values below the daily standard, with values ranging from 21.4 to 32.9 μg/m^3. At the remaining nonattainment site in Bakersfield, the 2019 design value declined to 35.7 μg/m^3.

Additional SIP modeling was done to assess the sensitivity of potential further actions to bring the remaining Bakersfield site into attainment. This modeling, as well as review of the emissions inventory in the area surrounding the Bakersfield monitoring site, identified the benefit of additional reductions in direct $PM_{2.5}$ from commercial cooking operations. The addition of this strategy was enough to bring the design value down to 35.1 μg/m^3, which meets the compliance benchmark of 35.4 μg/m^3 or less.

Modeling Results

The attainment strategy for the 24-hr $PM_{2.5}$ standard rests on a strong scientific foundation, including air quality data analysis and modeling. The modeling process began with an assessment of ambient data for $PM_{2.5}$ and its precursors, and consideration of meteorological variability in the selection of a SIP base year. The year 2007 was selected, since it included extended stagnation periods especially conducive to $PM_{2.5}$ formation and accumulation. Meteorology fields were prepared with the Meso-scale Model 5 (MM5), emissions were developed with in-house software together with the U.S. Environmental Protection Agency's (EPA) SMOKE package, and the photochemical modeling was conducted using EPA's Community Multi-scale Air Quality (CMAQ) model. CARB staff also consulted academic experts on prognostic meteorological modeling and photochemical PM modeling.

The $PM_{2.5}$ SIP modeling results showed that direct $PM_{2.5}$ is by far the most effective pollutant to control followed by NO_x, ammonia (NH_3), oxides of sulfur (SO_x), and volatile organic compounds (VOCs). Table 2 on the following page shows their efficacies on an absolute and a per-ton basis at the Bakersfield monitor based on SJV-wide emission reductions. As shown in Table 2, direct $PM_{2.5}$ controls are approximately four times more effective on a per-ton basis than NO_x controls, but a combination of the two is necessary for attainment. It is worth noting that if the reductions were done on a local basis, direct $PM_{2.5}$ controls can be as much as eight times more effective than NO_x controls. While SO_x reductions were as effective as NO_x reductions, the total tonnage of SO_2 emissions and the small percentage of sulfate in the ambient measurements (see Figure 2) are not sufficient to trigger the need for further SO_x controls. However, we note that sulfates contribute more to $PM_{2.5}$ in the SC air basin and controlling sulfur emissions is still a viable control strategy in that region.

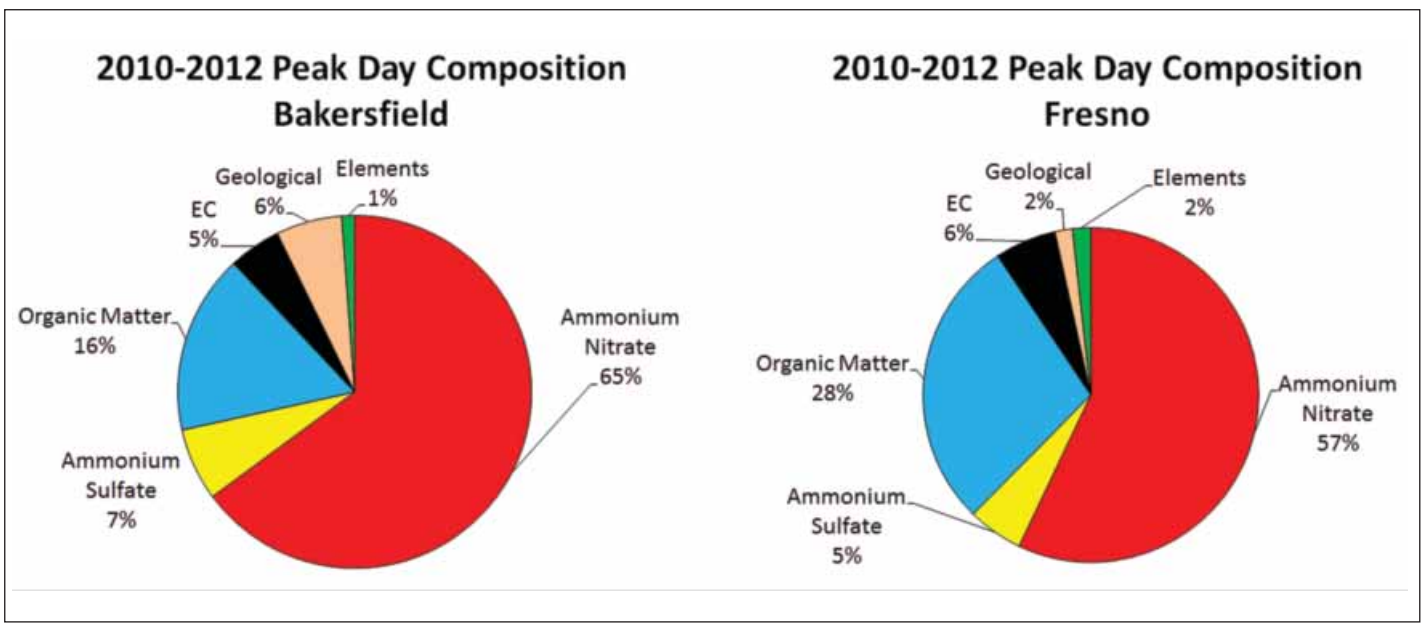

Figure 2. The average $PM_{2.5}$ chemical composition of the peak days of 2010–2012 at the (a) Bakersfield – California Street and (b) Fresno – 1st Street monitoring sites in the SJV.

Table 2. Modeled effectiveness of reducing 20% direct $PM_{2.5}$ and precursor gases on $PM_{2.5}$ levels.

Pollutant Emission	$PM_{2.5}$ Reduction ($\mu g/m^3$)	$PM_{2.5}$ Reduction/ton ($\mu g/m^3$)
Primary $PM_{2.5}$	4.44	0.34
NO_x	3.75	0.08
NH_3	0.55	0.008
SO_x	0.18	0.08
VOC	-0.10	-0.001

Notes: The first column lists the pollutants emitted, the second the absolute reduction in $PM_{2.5}$ due to a 20% reduction of that pollutant, and third the $PM_{2.5}$ reduced per ton of pollutant emission reduction.

The finding that NH_3 is not a significant precursor is consistent with the fact that it is in excess in SJV. Due to the lack of photochemical activity during the winter (because of the reduced amount of solar radiation), VOCs are also not a significant precursor. There is sufficient background ozone (approximately 50 parts per billion) during that time to produce nitric acid without VOCs.

The detailed modeling confirms that the most effective control strategy for 24-hr $PM_{2.5}$ in SJV is to reduce direct $PM_{2.5}$ emissions together with NO_x, which is consistent with the federally approved SIP for the annual $PM_{2.5}$ standard.

As discussed previously, the new measures in the SIP include a regional enhancement to SJVAPCD's residential wood-burning curtailment program, along with further control of emissions from commercial cooking operations to address the remaining localized nonattainment problem in the Bakersfield area. The SJVAPCD's current residential wood-burning curtailment program is in place during the peak $PM_{2.5}$ season of November through February, with mandatory restrictions on burning on days when high $PM_{2.5}$ concentrations are predicted. The program prohibits use of wood-burning fireplaces and wood-burning heaters when air quality is forecast to be above a 30 $\mu g/m^3$ threshold. The initial SIP modeling included the current program with an enhancement designed to further restrict burning on days that have the potential to contribute to the episodic build-up of $PM_{2.5}$ to levels that would exceed the standard. To implement this enhancement, SJVAPCD is considering a curtailment threshold of 20 $\mu g/m^3$ and expanding the program to include the months of October and March.

SJVAPCD also plans to strengthen its rule for commercial cooking operations. The current rule requires catalytic oxidizers for chain-driven charbroilers, including those used in many typical fast-food restaurants. The rule does not include under-fired charbroilers, but research and demonstration projects are currently underway to evaluate emission control technologies for these types of operations. SJVAPCD is collaborating with SCAQMD on this effort to investigate the economic feasibility and availability of such controls to support a rulemaking in 2016.

Summary

California's successful $PM_{2.5}$ attainment strategy is the result of strong science, comprehensive regulatory programs, and investment in early introduction of cleaner technologies. It was essential to understand the nature of the regional $PM_{2.5}$ problems in the SC and SJV regions, including their similarities and differences. The science demonstrated the relative effectiveness of reducing $PM_{2.5}$ and its precursors. The findings that reducing NO_x and primary $PM_{2.5}$ is a priority in both areas provided CARB with clear regulatory goals as the statewide rules for diesel fleets were developed. While the rules were designed to address multiple goals, including reducing cancer risk, the compliance deadlines for $PM_{2.5}$ and ozone standards helped set the pace of implementation.

California's incentive programs to accelerate the introduction of cleaner diesel engines are also

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essential to the success of the $PM_{2.5}$ attainment strategy. From 1998 to 2012, the Carl Moyer Incentive Program has been funded at more than $700 million statewide. These public funds are used to incentivize the early replacement and retrofit of vehicles and engines. California Proposition 1B has also funded more than $500 million in clean technology projects that reduce health risk from diesel particulates and provide $PM_{2.5}$ and ozone benefits.

A combination of regulatory actions and incentive programs have reduced $PM_{2.5}$ and NO_x emissions from on-road vehicles (e.g., trucks, buses, and transport refrigeration units), from off-road vehicles/equipment (e.g., construction equipment, agricultural tractors, cargo handling equipment, recreational watercraft, commercial harbor craft, and ocean-going vessels), and from stationary generators and agricultural irrigation pumps. The scope of these programs to clean up diesel engines reflects the significance of their contribution to local community health risk and attainment of $PM_{2.5}$ and ozone air quality standards.

These actions have resulted in significant progress in reducing exposure to $PM_{2.5}$ not only in SC and SJV, but throughout the state. Most of the California's population now lives in communities that are in attainment of EPA's recently revised annual standard of 12 $\mu g/m^3$, and continuing progress toward full compliance is expected with ongoing implementation of CARB's programs. em

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References

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